


BASE RECORDING: GATHERING INFORMATION

Rapid Assessment

Anthony Crosby

Historic earthen adobe buildings from the Spanish Colonial and Mexican Federal periods are the only remains of settlements from the eighteenth and nineteenth centuries in the Los Angeles area. Invaluable reminders of California's past, they are extremely vulnerable to earthquakes. In January 1994, an earthquake of Richter magnitude 6.4 struck an area in which many of these historic earthen structures exist.

How can a team make informed evaluations quickly of these structures and their seismic performance in order to better protect them in the future?

This illustrated example was completed with the assistance of Leroy Tolles and the staff of the Getty Seismic Adobe Project. They provided images and details of the work to complete this example.

Southwest corner of the Rancho Camulos Adobe after the 1994 Northridge earthquake in the Los Angeles area. Photos of historic structures taken immediately after disasters but before cleanup or stabilization can aid engineers in understanding the causes of structural failure. Photo: © Rancho Camulos Museum, 1994.

Los Angeles, California

Historic missions, ranch complexes, and simple houses are scattered throughout Southern California in the Los Angeles basin, the San Fernando Valley, and the San Gabriel and Santa Clara river areas. The semiarid climate, the relative scarcity of timber, and a culture of building with sun-dried mud bricks led to the first immigrants' decision to build their dwellings and religious buildings with adobe. Often these buildings were constructed on soft soils, such as alluvial deposits and unconsolidated sediments. This combination of adobe buildings on soft soils in a seismically active area proved unfortunate.

In the early 1990s, concerned conservation professionals feared that many of California's historic adobes were being seismically strengthened using overly aggressive and damaging methods. In response, these professionals, along with the Getty Conservation Institute, launched the Getty Seismic Adobe Project (GSAP). A project team and advisory committee were formed that consisted of these professionals as well as architects, engineers, university professors, and project managers.

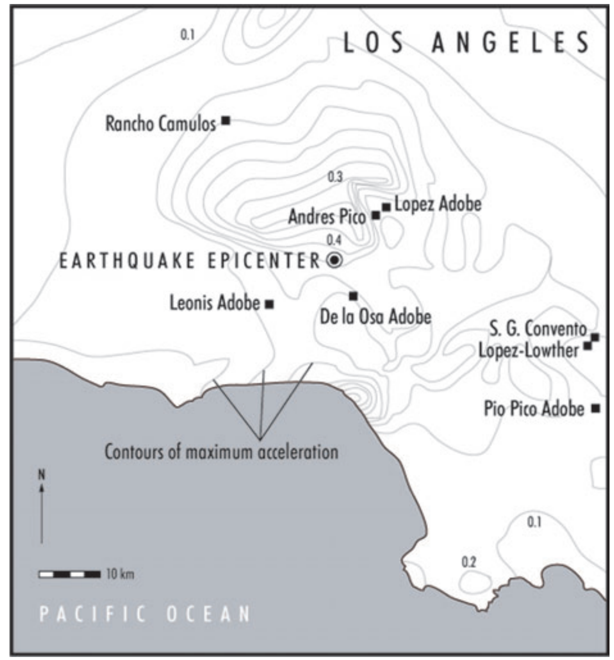
The program's goals were to develop less invasive strengthening methods and produce guidelines for their implementation. The project began by evaluating existing methods and examples of seismic reinforcement with a view toward both life safety and protecting the authenticity of historic buildings. The team took advantage of previous research and specific projects that appeared to address seismic criteria in responsible and sensitive ways. The research also included theoretical and mathematical analysis and extensive shaking-table tests of one-tenth and one-half scale model adobe structures.

The advisory committee met periodically with the program team and project managers to review the progress. One of several recommendations made was to incorporate additional field analysis of historic adobe structures and to study actual failure patterns. This recommendation was incorporated into the program, and in late 1993 field studies were undertaken. The participants in the field analysis were two structural engineers, a material scientist, an architectural historian, and the author, a conservation architect.

On January 17, 1994, the most damaging earthquake to strike the Los Angeles metropolitan area to date occurred. The historic adobes nearest the epicenter, in Northridge in the San Fernando Valley—Andres Pico, De la Osa, Rancho Camulos, and Lopez, as well as the San Fernando Mission Convent—were subject to very strong ground motions of more than 0.4 g. Fifteen other historic earthen structures, including the San Gabriel Mission Convent, were also affected but are located farther away, where the ground motion was significantly less.

Because many of the earthquake-affected adobe buildings had been studied only months earlier, the aftereffects of the Northridge quake provided a unique real-world laboratory. Action was taken immediately, and within a week the original team was back in the field to undertake a rapid assessment and reevaluation of the historic adobes. The effort was supported by the State Historic Preservation Office (SHPO), California State Parks, private and public property owners, and the GSAP. It was critical that assessment of the damage take place as soon as possible after the earthquake, before additional aftershocks, rain, or demolition for life safety erased evidence or unnecessarily removed original sections of the buildings.

The two main objectives of the rapid assessment were (1) to quickly document and evaluate the buildings that were at greatest risk and (2) to record the failure patterns so that an understanding of the relationship between the failures and the earthquake characteristics could be developed and later utilized in the overall GSAP goals of providing guidelines for less invasive seismic retrofits.



Map of Los Angeles, showing locations of historic adobe structures, the quake's epicenter, and contours of maximum acceleration. A map like this was used in planning site visits to the affected area. Drawing: Steven Rampton.

Sketch Diagrams

The rapid assessment began with the identification of buildings that had been damaged or potentially damaged in the earthquake. The SHPO, California State Parks, and building owners were contacted directly for information on the buildings' status. Locations were noted on a map, and site visits were planned to evaluate as many buildings as possible in the shortest amount of time.

All travel was conducted by automobile, and the time spent in transit provided valuable opportunities to discuss each building, preview useful information, and develop a tentative assessment plan. While these conversations were cursory, they nonetheless added to the collective understanding of the structures and proved extremely valuable as an efficient planning method.

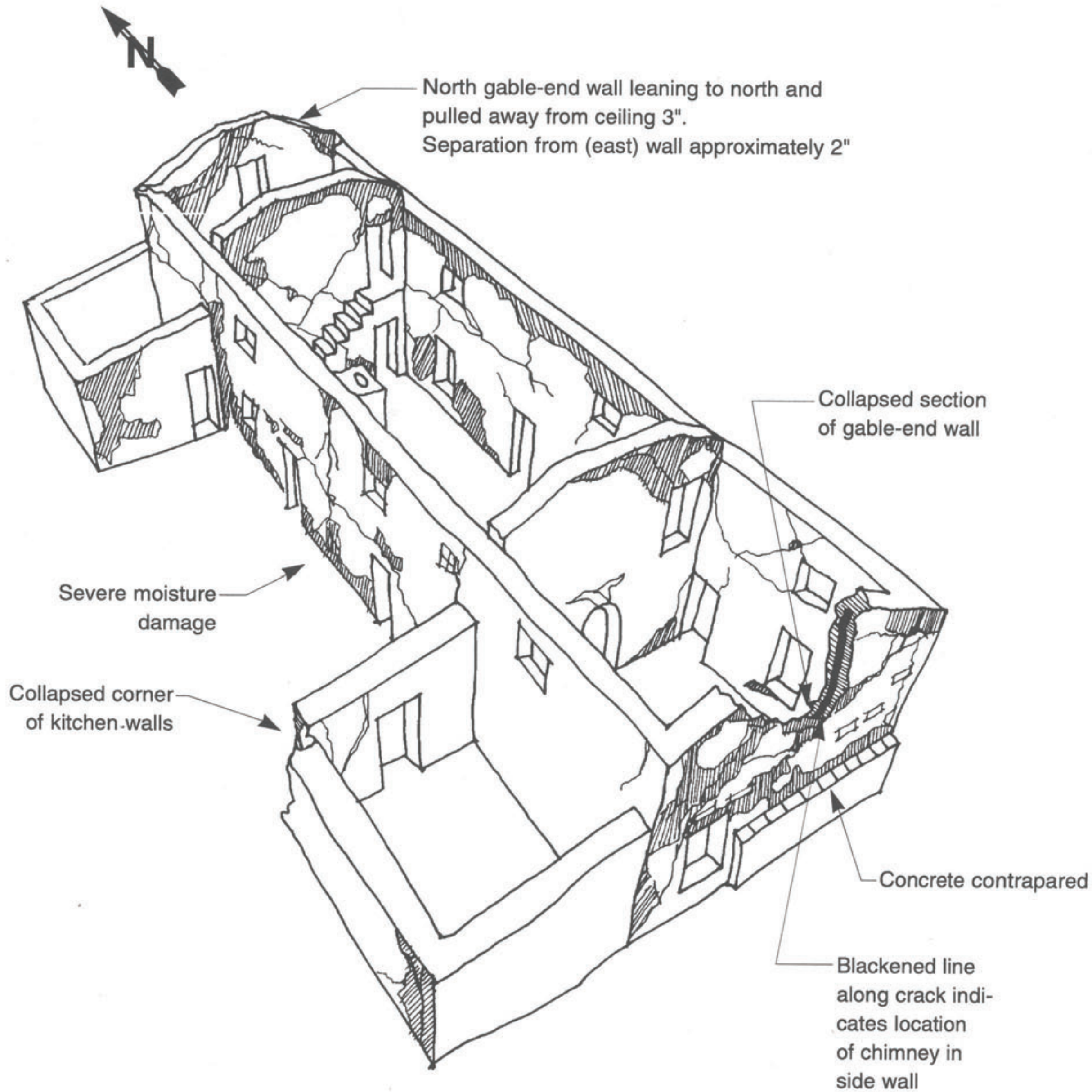
The next step in the assessment was for the five participants to survey the site as a group, then to split up and, individually or in smaller groups, collect as much information as possible. After the individual assessments, there were brief meetings to review findings and discuss building failures and their possible causes. It was important to understand which failures may have been preexisting and whether these preexisting conditions (moisture damage, previous crack damage, or previous repairs and retrofit measures) may have contributed to the failures. One very important aspect of the assessment was to develop a clear understanding of the performance of the entire building system.

Time spent at each building site depended on the overall schedule, size, and significance of the structure, degree of damage, and complexity of the failure patterns. In one case, the assessment of a heavily damaged, simple one-room structure

East exterior elevations of the Andres Pico Adobe, after initial structural assessment. Structural failures such as cracks caused by out-of-plane flexure were sketched on top of 35mm film and Polaroid images that were taken perpendicular to the building. This type of on-site assessment allowed engineers and architects to compile the final synthesis analysis and quickly move on to the next building. Photo: E. Leroy Tolles.

Before and after images of the Andres Pico Adobe. Photo: E. Leroy Tolles.

Final synthesis analysis sketch of the Andres Pico Adobe. This perspective sketch, completed just weeks after the earthquake, allowed engineers and architects to understand all of the failures and interaction of building elements at a glance. Drawing: Anthony Crosby.



required only a few minutes; in other cases, the assessment took several hours. Work began early in the morning and lasted until dark.

When available, existing drawings and photographs were annotated to plot, interpret, and analyze the extent and patterns of damage, and to note construction details. When these were not available, field sketches were used. What proved to be particularly valuable were the notes, photographs, and field sketches of conditions prior to the earthquake from earlier GSAP studies. In several cases, the identification in the earlier study of preexisting structural cracks provided a much clearer understanding of the effects of the earthquake.

Small-format (35mm) photography (color and black and white), Polaroid, and video were also used. Scaled photographs of key wall elevations were assembled and used with field notes to plot crack damage. Video was used to record an overview of the general conditions and capture spoken observations of specific details—this was often faster than writing down the same observations. Elevations, perspective drawings, and sketches were used to record information and plot failures not visible in photographs. Simple hand tools such as a plumb, an optical hand level, and a straight or bubble level were used to quantify some of the field data. Within a period of six days, nineteen structures were evaluated, numerous sketches created, and more than five hundred photographs and four hours of video taken.

Immediately following the fieldwork, the data were reviewed by team members in order to refine their understanding and develop a "failure typology." However, more time was needed to fully comprehend the effects of the earthquake on the adobe structures. Approximately two additional months were spent assimilating the data and relating earthquake characteristics and preexisting building conditions to individual failure patterns.

It soon became clear that a forum was needed to share this information and discuss the findings of the team. A one-day mini-conference was organized within a year of the earthquake, and the results of the rapid assessment and failure typology were presented to other engineers, architects, and building professionals. Case studies of strengthened and nonstrengthened adobe buildings, and the impact of preexisting conditions and building histories on failure patterns, were presented as well.

Though it was never the original intention to produce a formal detailed publication of the results, eventually it became clear that such a report would be valuable to others. Several months were spent further evaluating the data and drawing conclusions, resulting in the publication *Survey of Damage to Historic Adobe Buildings after the January 1994 Northridge Earthquake*. A PDF edition of this book is available at www.getty.edu/conservation/publications/pdf_publications/books.html.

An Answer

The Northridge earthquake revealed on a large scale the vulnerability of historic adobe buildings to seismic forces: vulnerability that can be mitigated through seismic strengthening without being overly aggressive or damaging the buildings. The rapid assessment documentation assisted the project team in understanding the performance of adobe structures during seismic events and led to establishing guidelines on stabilization and strengthening. The conclusions determined that preexisting conditions had a major impact on the structural behavior of the buildings, and that preparations for future earthquakes must be made. Further questions were raised about earthen structures in past earthquakes, and additional studies were suggested. These findings were communicated to building code officials, building owners, and the SHPO.

The conclusions also showed the value and effectiveness of conducting such a survey soon after the earthquake using only basic tools and equipment. More sophisticated equipment simply was not needed, as the study and analysis were conducted by an experienced multidisciplinary team. While it may have been beneficial to include additional team members, there was not enough time to organize and train a larger team who would have had only a minimal understanding of the buildings and their failures. With less experienced team members, the collection of data would have taken longer and would have had to be more comprehensive and accurate if it was to be interpreted by others.

In 2000, the GSAP was completed, resulting in the publication of *Seismic Stabilization of Historic Adobe Structures* and *Planning and Engineering Guidelines for the Seismic Retrofitting of Historic Adobe Structures* (PDF editions of these books are available at www.getty.edu/conservation/publications/pdf_publications/books.html). The rapid assessment of historic adobe buildings after the Northridge quake greatly contributed to these publications and to the overall project. Another benefit of the project was the publication of a detailed report that resulted in the subsequent conservation and seismic strengthening of the heavily damaged Rancho Camulos Adobe, in Ventura County. Many other damaged adobe buildings in and around Los Angeles have since been conserved using the guidelines produced by the GSAP.

Anthony Crosby is an architect specializing in the conservation of earthen construction. He has many years of experience working for the U.S. National Park Service and internationally in the Middle East. He was a member of the GSAP advisory committee and is based in Denver, Colorado.

Southwest corner of the Rancho Camulos Adobe, after rehabilitation. Data collected during the rapid assessment were used to design earthquake mitigation techniques and devices that can be used on other historic earthen structures. Photo: Gail Ostergren.

Wall Deformation

Sandeep Sikka

The Buddhist temples and monasteries in the western Himalayan regions of Spiti and Kinnaur, India, have survived for nearly a thousand years. Today, they are susceptible to innumerable natural and man-made threats. Seismic vibrations, changing climate, and improper interventions have caused serious damage to these historic earthen structures.

How can a simple and effective tool record impending wall failures and assist in designing treatments for these buildings?

The earthen structures of Dhangkar Gompa, a Buddhist monastery in the western Himalayas, have survived for nearly a thousand years but are under threat from inappropriate interventions, seismic vibrations, and a changing climate. Photo: © Marek Kalmus, 2005.

Spiti and Kinnaur, India

Perched high in the mountains of Himachal Pradesh, numerous Buddhist monasteries dot the landscape. Buddhist architecture evolved as builders struggled with the region's harsh climate, hostile invaders, and meager resources. Built of rammed earth or sun-dried adobe blocks on rubble foundations, the structures are simple and symmetrical in plan. The walls of most temples are devoid of any openings, and the only source of light and ventilation is provided by small openings in the ceiling or at the entrance. The flat roofs are made of compressed mud layered on a mesh of willow twigs supported by wooden beams set on columns and load-bearing mud walls. The interiors are intricately decorated with paintings applied on the smooth mud-plastered walls and ceiling panels, while beautiful earthen sculptures are attached to the walls with wooden plugs or mounted on stone slabs. Local inhabitants revere these religious complexes, which have remained active places of worship since their construction nearly a thousand years ago. The sites are used for local ceremonies and festivals as well as major religious gatherings, such as the festival of Kalachakra, hosted by His Holiness, the Dalai Lama.

Deterioration of the structures has rapidly increased within the last fifty years. Inappropriate repairs, insufficient maintenance, increased rainfall, and frequent earthquakes threaten their very existence. A project to save these important treasures was launched in 1999 and supported in part by UK–ICOMOS (United Kingdom–International Council on Monuments and Sites) and the Museum of Archaeology and Anthropology, University of Cambridge. The project was designed in five phases: preliminary investigation, risk assessment and measured survey, evaluation, conservation implementation, and maintenance. The first two phases were crucial, as they guided the overall course of the project and determined which structures were at greatest risk.

The first phase, preliminary investigation, was conducted by a large team of architects, historians, wood and painting conservators, material scientists, and engineers–twenty in all. This was a rapid inventory that mapped locations and assessed the significance of and immediate threats to more than twenty individual structures and their components. Photographs were taken, notes and sketches made, and plans laid for the second phase later that summer. Planning was critical, as access to this remote region is difficult due to narrow mountain passes, rough roads, and deep snow. Only two field visits per year could be carried out during the summer: after the snow thaw, and before the first snowfall. Just two months were available for the preliminary investigation, and three months for the next phase; therefore, work had to be organized and accomplished quickly.

The second phase, detailed risk assessment and measured survey, was more difficult. There were no previous archival drawings or records of these buildings, and the team's budget was extremely limited. Complicating matters was the small size of the survey team, composed of only one trained architect, two conservators, and four local workers. The goal of this second visit was to examine four of the structures at greatest risk (Dhangkar Gompa, Chango, Nako Temple complex, and Mantra Chakara, also known as Dhungur Lhakhang), determine the causes of deterioration, identify and map major structural issues, and create architectural drawings. Accomplishing these goals was crucial to the success of the overall project, because the results were intended to help other members of the team and serve as the basis for understanding and planning the conservation strategy. Given these parameters, the project needed low-tech tools and a simple documentation technique.

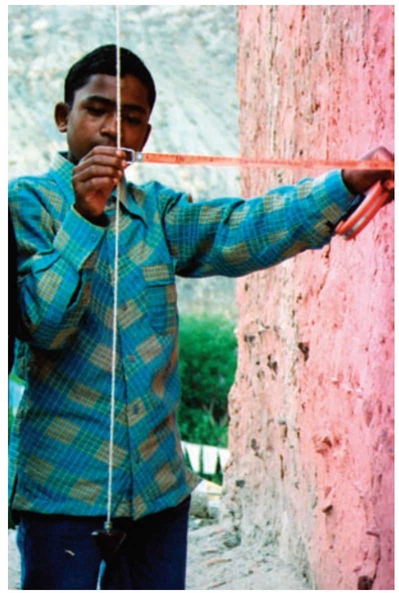
Interior of the Lotsawa Lhakhang Temple. Sculptures, decorations, and painted surfaces inside the temples and monasteries are threatened. Photo: © Sandeep Sikka.

Hand Survey

The buildings and wall profiles were measured manually with 50-meter steel measuring tape, string, pencil and graph paper, architectural scale, right angle, and plumb bob. Manual recording techniques, although often labor intensive, are readily available and allow conservators to study buildings in great detail. Usually this method of recording provides detailed information and sufficient accuracy to begin conservation of earthen structures. Other survey tools, such as a total station theodolite, were considered; however, this equipment was unavailable and did not fit the budget, and no one on the team had the expertise.

Measuring began by establishing two datum, or station, points. These are semipermanent markers created in the earth with large nails on the interior and exterior of each structure. Both of these points had to be seen in a straight line through the only door. These points formed a baseline that allowed the measurements taken on the interior to align with the measurements taken on the exterior. Supplemental reference lines were created along the interior and exterior walls parallel and perpendicular to this baseline using the right-angle tool. The right-angle tool is two 30-centimeter-long rectangular pieces of metal connected at exactly 90 degrees. These supplemental reference lines were made with a tightly stretched string held against the right angle and baseline. The string had been dipped in blue indigo dye, which, when dry, created a powder that transferred to the ground. The station points, baseline, and reference lines were then measured with the steel tape, and a plan was drawn to scale on graph paper.

Using a plumb bob and string, the intersections of these lines were transferred vertically. A plumb bob is a pointed weight of between 100 and 500 grams that, when hung from a string, creates a vertical reference line and allows the user to transfer points or lines. Horizontal strings were stretched taut and reference lines made on the ceiling and parapets. The plumb bob was suspended with a string knotted every 50 centimeters, and the wall deformations were measured with the steel tape from every knot to the wall. The plumb bob and string were then moved 50 centimeters horizontally for another set of measurements. This, in effect, created a grid of measurements that mapped the wall deformations. A modular grid of 50 centimeters was chosen in order to obtain an appreciable curve of the bulges and closely corresponded to three courses of adobe masonry. This grid was helpful in generating plans and sectional profiles of the walls, clearly showing bulges and other deformations. It allowed the architects to get a comprehensive picture of the buildings and any potential failures.



A worker measuring exterior deformation in reference to a vertical plumb line at Chango Temple. Photo: © Sandeep Sikka.

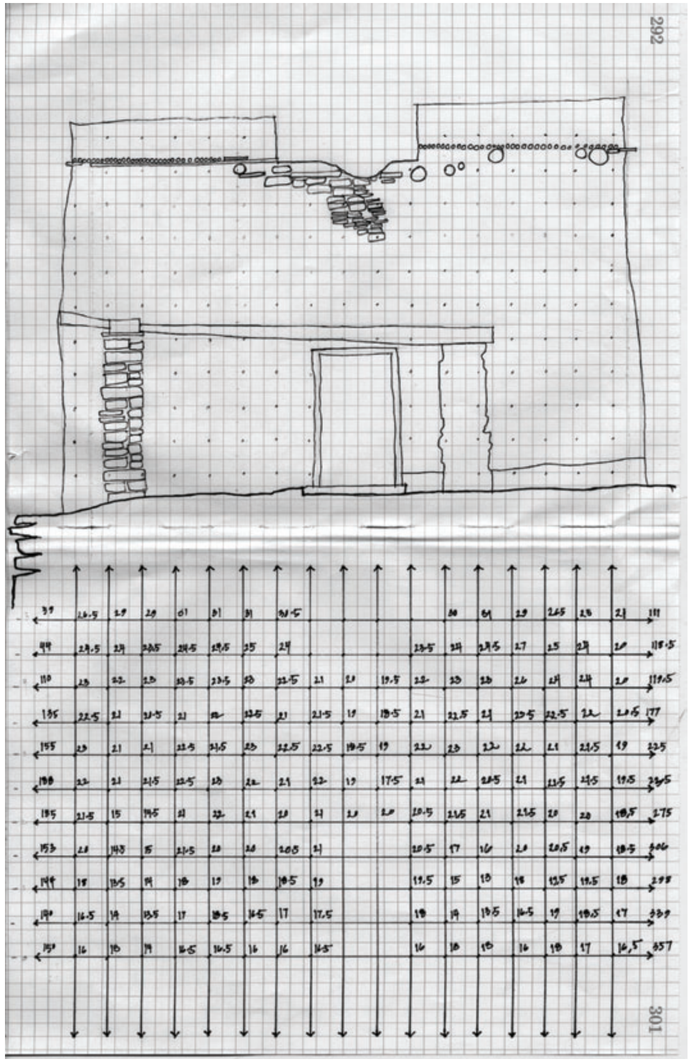
All sheets containing the sketches and measurements were labeled with building identification numbers and marked with directions and detailed notes. When the team returned to New Delhi, all drawings were photocopied and the originals retained by the lead architect. The points and measurements were entered into AutoCAD, a computer drafting program, which provided a final check on the measurements. If discrepancies existed between interior and exterior measurements, the building was scheduled for remeasurement the following spring. Following this process, plans, sections, elevations, and wall profiles were created and distributed to the architects and engineers to devise a strategy for structural conservation.

A local worker recording the front elevation of Chango Temple. Manual recording techniques, although labor intensive, are readily available and allow conservators to study buildings in great detail. Photo: © Sandeep Sikka.

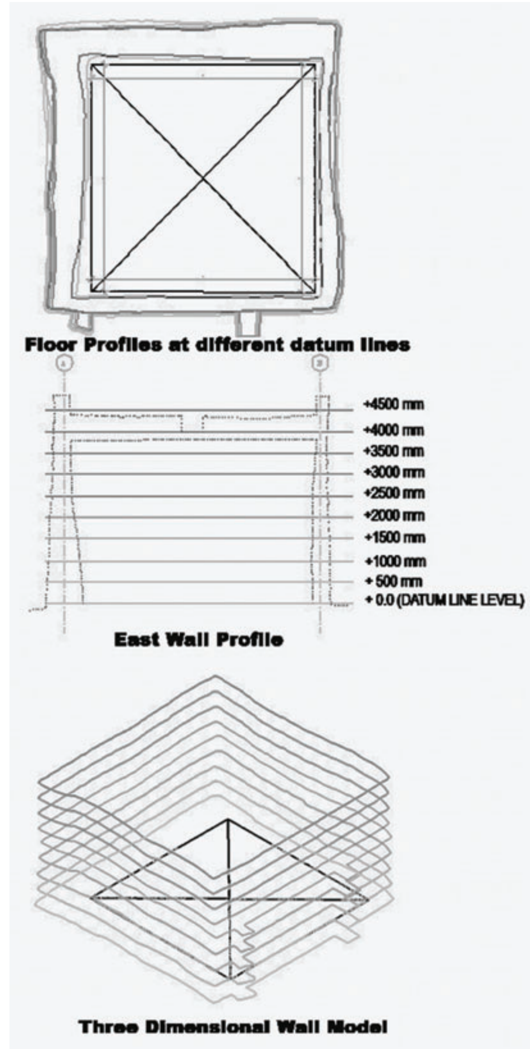
Some problems arose using this process. When the interior and exterior drawings did not align, the measurements had to be completely repeated for the entire building. The indigo-dye reference lines were not permanent and faded after a short time. Also, the 50-centimeter measuring grid could have been adapted to allow for the recording of smaller deformations. The reverse was also true: if a wall was relatively straight, fewer measurements could have been taken, speeding up the process. A heavier plumb bob, greater than 200 grams, should also have been used, as high winds disturbed the exterior vertical reference line. Another tool that could have improved accuracy was a bubble line level to ensure that the reference lines were exactly horizontal.

The hand-measuring method used to record these buildings can be used anywhere with minimal training. The tools involved should be a standard part of every architect's or engineer's equipment and cost very little. If conducted in an organized and systematic way, the results are sufficient to produce good, usable drawings.

During the next phase, evaluation, the drawings and wall profiles generated from these measurements showed outward movement of the upper courses of the walls due to excessive roof loads. Increased precipitation in the region over the last few years prompted local craftspeople to waterproof the roofs by adding layers of compacted mud. These additional layers have drastically increased the roof load, resulting in either sagging of structural members or outward movement of the walls near the ceiling. The drawings also showed outward bulging in several places at the bottom of the walls in the interior. This was caused by excessive moisture swelling the ground outside the buildings, creating a lateral thrust on the lower masonry courses.

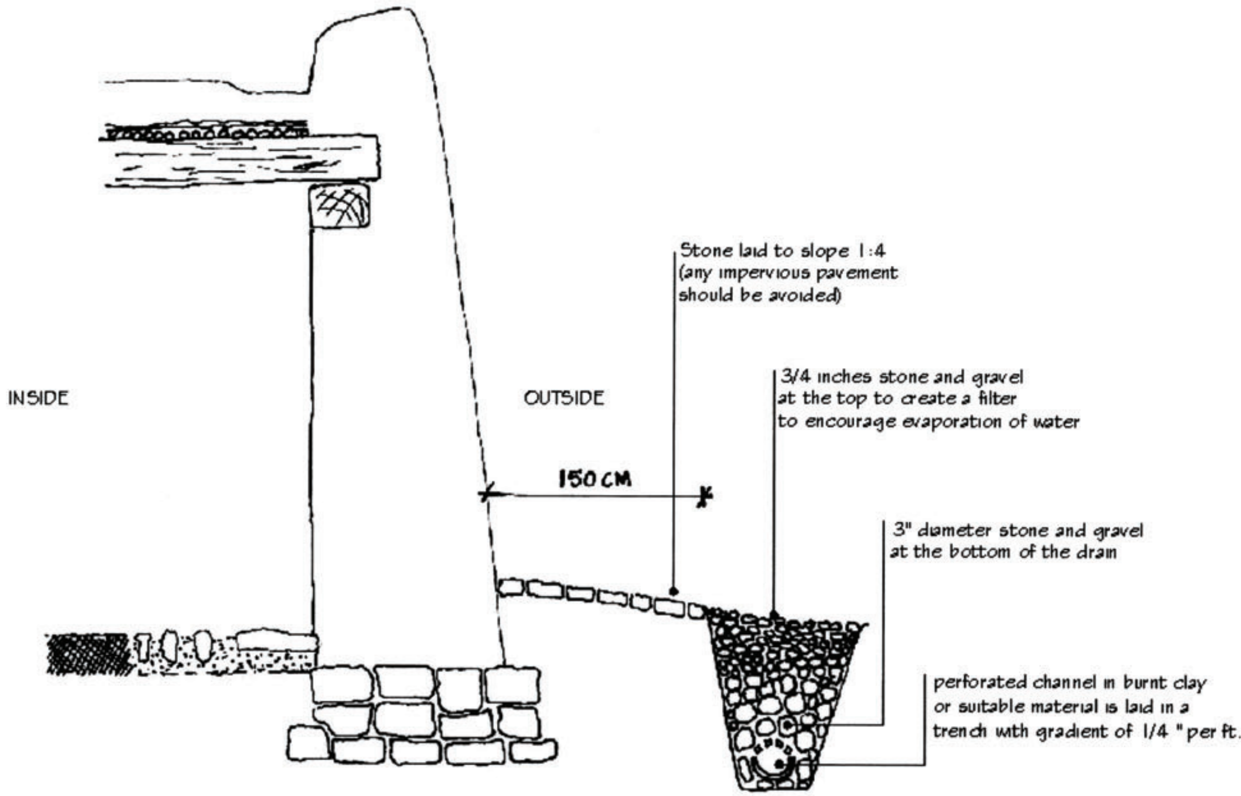


Hand-drawn front elevation of Chango Temple, showing all out-of-plumb measurements at every 50 centimeters. Recording the wall deformation assisted conservators in understanding the causes of deterioration. Drawing: © Sandeep Sikka.



The manually recorded measurements were entered into AutoCAD, a computer drafting program, for further analysis. Drawing: © Sandeep Sikka.

Bulging walls and structural cracks developed due to the horizontal thrust from the surrounding groundwater. Issues of drainage were resolved by sloping earth away from the walls and burying perforated drains. Drawing: © Sandeep Sikka.



Workers burying perforated drains. Photo: © Sandeep Sikka.

An Answer

In the conservation implementation phase of the project, the extra layers of compacted mud were carefully removed from the roof and one thin layer of mud added. Point loads created at the junction of wooden beams and the wall were addressed by inserting continuous wood wall plates to distribute the load more evenly over the entire wall top. Issues of drainage were resolved by sloping earth away from the walls and burying perforated drains to remove the excess water and avoid further stress on the structure. After the structures were stabilized, conservation was conducted on the wall paintings and wood. The final phase, maintenance, was educational and enabled local workers to maintain the structures.

The process of measuring the wall deformations allowed the architect and conservators to become intimately familiar with the buildings. This work and the resulting drawings assisted the project team in forming theories of deterioration and planning the conservation work. The drawings also established a starting point for maintenance and monitoring so that these important religious structures can serve their communities for another thousand years.

Sandeep Sikka is a conservation architect from India currently working in New York. He is a Charles Wallace Conservation Scholar and is completing his PhD studies at the University of Applied Art Institute for Conservation and Restoration, in Vienna. He has studied and worked on the conservation of several historic earthen structures and vernacular architecture in the Indian Himalayas. He was awarded the Frederick Williamson Memorial Grant from the Museum of Archaeology and Anthropology, University of Cambridge, England, and a UK–ICOMOS research scholarship to conduct the work described in this study.

Defining Cultural Landscapes

Geofree Chikwanda

In the Shona tradition of Zimbabwe, great ancestral spirits are responsible for overseeing the well-being of entire regions. It is a commonly held belief that if a natural place is degraded, the ancestral spirit deserts the region and misfortune befalls the community. Natural places anchor those who inhabit the land to their history and culture. They serve to remind people of important events and educate new generations. Preserving these natural places helps to maintain these connections.

How can a cultural landscape be identified and defined to ensure its protection?

Traditional earthen huts of the spirit medium Nehanda Charwe Nyakasikana, in Shavarunzi, Zimbabwe. Photo: © Geofree Chikwanda.

Shavarunzi, Zimbabwe

Mbuya Nehanda, one such nationally recognized ancestral spirit, was a woman who honorably influenced Zimbabwe in the late fifteenth century. In the early 1890s, Nehanda Charwe Nyakasikana, a medium of the spirit Nehanda, was a principal leader in the resistance against British colonization. Upon the collapse of the resistance in 1897, Nyakasikana was arrested for her role in the ill-fated uprising and sentenced to death. Her prophecy that she would rise again was the main inspiration behind the second wave of resistance movements in the 1960s and 1970s that finally led to Zimbabwe's independence.

To this day, the Shavarunzi landscape and the homestead that Nyakasikana occupied are regarded to be of historical, spiritual, and patriotic importance. Strewn with granite hills and ironstone mountains, the area is closely associated with the traditions of the Zimbabwean people and their struggle for independence. This culturally important region, 25 kilometers north of the capital city of Harare, covers more than 17,000 hectares and contains the third largest dam in the country. A contemporary spirit medium, together with her aides, currently occupies a homestead at the foot of one of the hills, where annual ritual gatherings are held to celebrate the symbiotic relationship between nature, history, and the people.

A large portion of this cultural landscape is composed of prime farmland and valuable mineral deposits, including gold. Since the advent of the national land redistribution program in 2000, there has been a steady influx of illegal settlers from the adjacent Domboshava communal lands to the east. Settlements, which are considered taboo, have even been established on the eastern side of Shavarunzi

Sketch of Mbuya Nehanda, a nationally recognized spirit who influenced Zimbabwe in the late fifteenth century. Drawing: M. I. Mashamaire.

Hill, near the current spirit medium's residence. In addition, wealthy individuals from Harare and the nearby mining town of Bindura, 50 kilometers to the north, have set up mining operations in the area. Heavy excavation machinery has been brought in to quarry gravel and mine gold, and blasting has commenced. These burgeoning settlements and mining activities threaten the spiritual and environmental integrity of the landscape. As the traditional custodians of the land, the spirit medium and her aides approached the Zimbabwean government's Ministry of Mines, Environment and Lands, as well as the Ministry of Home Affairs.

To protect this important cultural landscape, the spirit medium and her aides, in collaboration with the organization National Museums and Monuments of Zimbabwe (NMMZ), initiated a humble, diplomatic dialogue with the settlers and miners in 2002. It was hoped this approach would encourage respect for the landscape and dissuade exploitation. These discussions were also intended to avoid a backlash from the settlers and miners, who might have felt they were being bullied. At the same time, it was recognized that the landscape and the spirit medium's homestead deserved a rightful place on the country's national heritage register and thus should gain legal protection. NMMZ can invoke official protection only if the landscape is clearly defined and declared a national monument; therefore, a delimitation exercise was needed to identify important sites and boundaries.

The delimitation project was organized into four parts. First, dialogue continued with the various stakeholders, including farmers, miners, settlers, and the spirit medium and her aides. It soon became apparent that this dialogue not only was an important entry into protecting the land but also

Illegal surface strip mining for gold and other minerals using heavy equipment and blasting has disrupted the natural landscape. Photo: © Geofree Chikwanda.

Illegal settlements, often considered taboo, encroach upon the ancestral landscape. These settlements threaten the spiritual integrity of the cultural landscape. Photo: © Geofree Chikwanda.

was helpful in identifying boundaries and features such as important hilltops, roads, and corrals. The spirit medium and her aides knew the area and its significant landmarks better than the surveyors, settlers, or miners did. During this dialogue, research was undertaken by a number of government departments to collect old maps that could serve as a starting point for fieldwork. Using these maps, survey data were collected in three separate visits over the course of one year. Finally, all information collected was processed to create a new set of maps, which became part of a legal document presented to the government calling for protection of the landscape.

Total Station

The main tools utilized for the field delimitation were a total station theodolite and a handheld global positioning system (GPS) receiver. A total station theodolite is a standard survey device that locates points by measuring distances as well as horizontal and vertical angles. It differs from a theodolite in that it measures not only angles but also distances and includes an onboard computer.

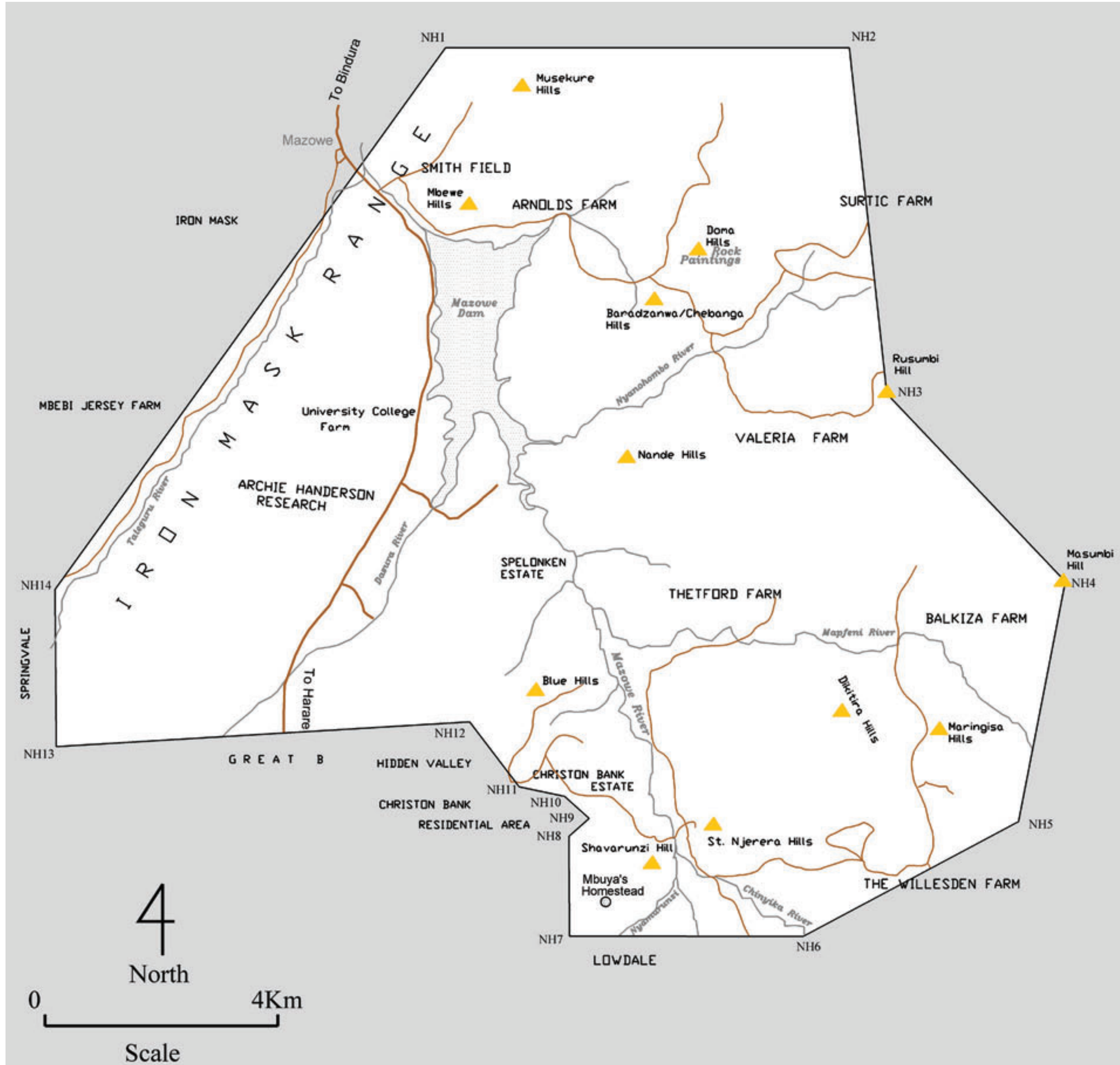
The total station theodolite used in this survey was a Topcon GTS200 series. Placed atop a tripod, it consists of a powerful telescope mounted on a base that rotates both horizontally and vertically. Features such as roads, buildings, and property boundaries are identified by looking through the telescope at a prism or reflector target on a pole held by another surveyor. These features can be as close as 2 meters or up to 5 kilometers away, depending on the telescope. When the surveyor focuses the telescope on the prism, the total station theodolite accurately records the horizontal and vertical angles and distance. Distance is measured with a feature known as electronic distance measurement (EDM). An infrared beam is projected from the total station theodolite, which "bounces" back to its source and, using a timing device, the distance is calculated. Many total station theodolites also have a mode known as reflectorless, meaning that within short distances of 100 meters or less, a prism or reflector is not needed. This allows the instrument to be operated by only one surveyor, which is useful when measuring points difficult to access, such as cliff faces or ridge beams. Trigonometric calculations are then performed by the onboard computer, combining the horizontal and vertical angles with the distance measurement to determine an XYZ coordinate, usually within a centimeter. By recording and then connecting many individual points, lines can be created that describe features such as walls, hills, or boundaries. To record all the features of a large area, the total station theodolite and tripod are moved to new locations, or setups, which are then combined to form a network called a traverse. Measurements taken from different station points along the traverse improve accuracy and allow the combination of all XYZ coordinates to form a complete survey.

The author using a total station theodolite. The total station and its onboard computer calculate the position of a point through trigonometry by recording the horizontal and vertical angles and distance. Photo: Rand Eppich.

The GPS receiver also calculates XYZ coordinates with trigonometry, but by receiving radio signals from orbiting satellites. Although it is not as accurate as a total station theodolite, it is much quicker and very useful in describing large features such as hilltops or rivers. The handheld GPS unit used in this survey was a Garmin 12 with an average accuracy of about 6 meters. Handheld units are generally inexpensive and easier to use but not as precise as professional units, many of which are equipped to receive ground-based radio signals. These signals can improve the accuracy of GPS units to a few centimeters by correcting for inaccuracies or radio signal loss from the satellites. The ground-based signal, called differential, is either sent from existing commercial radio station towers or navigational beacons, or transmitted from a station set up by the surveyors. Differential GPS units are now included in the newest models of total station theodolites to create a "complete" total station.

Field data were collected on three trips. On each trip, surveyors recorded more detailed information to add to the previous data. During these and all subsequent visits, the spirit medium was notified of the surveyors' presence and kept informed of all activities. On the first trip, two surveyors used only the handheld GPS unit with the existing maps (scales 1:5,000, 1:50,000, and 1:250,000). Throughout the initial reconnaissance, these maps were evaluated in consultation with aides to the spirit medium in order to identify the hills and other sites of cultural importance. The existing maps were found to be inaccurate, with many of the hills and landmarks misspelled or unidentified altogether. These sites, in addition to the residence of the current spirit medium, were visited and their coordinates recorded and marked on the maps. Fourteen survey markers (or boundary beacons) were erected at each corner point to delineate the extent of the proposed protected area.

Further field interviews with the aides were conducted during the second and third visits to locate additional areas. These features and the spirit medium's homestead were measured in more detail and with greater accuracy using a Topcon GTS200 total station theodolite. At each subsequent visit, corrections were made on the previous survey. Photographs of each area of interest were also taken throughout as part of the overall project.



Map of the proposed protected area of Shavarunzi, including boundaries, topographic features, settlements, and significant historical and cultural sites. Map: © Geofree Chikwanda.

An Answer

After field measurements were collected, the existing 1:250,000 base maps were scanned. The maps were then edited using AutoCAD 2000, a computer drafting program, to insert any missing features, correct misspellings, and add new measurements. Boundary points and proposed protection lines were also included. Once the first version of the maps was complete, it was reviewed by the surveyors and the spirit medium and her aides. Ethnographers and historians also reviewed the maps along with archival records, and compared this information with the oral evidence collected during the dialogue that had been initiated at the beginning of the project.

In 2005, the maps, oral evidence, and archival research helped NMMZ to craft a sound statement of significance for the proposed national monument. The inclusion of this landscape on the national monuments register is leading to the drafting of a management plan to address conservation challenges. In addition, it is crucial that the settlers and miners remain engaged and informed of the implications of these changes. Much work remains to be addressed, such as an assessment of the impact of new settlements spilling over from Harare, a systematic condition study of waterways, and an examination of the fauna and flora. Protecting this cultural landscape continues to be a large-scale and long-term task requiring an array of resources and the involvement of a variety of professionals and the local community. By defining its boundaries, however, the first step has been taken in protecting this cultural landscape and maintaining the connection between the people, history, and the land.

Geofree Chikwanda was a monuments surveyor for National Museums and Monuments of Zimbabwe, with more than ten years of survey experience using total station theodolites and GPS technology. He died in a tragic accident shortly after completing this work.

View of the endangered Shavarunzi landscape.
Photo: © Geofree Chikwanda.

Mapping Features

Jo Anne Van Tilburg, Cristián Arévalo Pakarati, and Alice Hom

Nearly nine hundred large stone statues, known as *moai,* dot the landscape of the eastern Pacific island of Rapa Nui (Easter Island). They were carved from basaltic lapilli tuff, a consolidated volcanic stone found on the island, primarily in a single crater known as Rano Raraku. The source for fully 95 percent of the known moai, Rano Raraku is a striking landmark partially filled with a marshy freshwater lake. Just over half of the statues carved in Rano Raraku were transported to every part of the 164-square-kilometer island, to be erected on ceremonial sites.

The tuff from which the statues were created is porous and susceptible to deterioration and weathering. That fragility, coupled with the fact that Rano Raraku is a major tourist destination, creates an urgent conservation imperative.

Given the size and steep terrain of the volcanic quarry and the large number of unfinished moai, how can a map be created that records both the location and features of these statues?

The crater of Rano Raraku, with its marshy lake in the background. Photo: Jo Anne Van Tilburg. © Jo Anne Van Tilburg/Easter Island Statue Project.

Rapa Nui

The Rano Raraku archaeological zone is just over 1 square kilometer, including the volcano and its immediately adjacent plain. The zone is located within Hotu Iti, the eastern and lower-ranked of two sociopolitical districts that emerged between 1000 and 1500. The tuff is arrayed in roughly horizontal bands and exposed in irregularly shaped flows (*papa*) on the north-facing upper side of the volcano's interior. The papa slopes 28 degrees in most places and is visually subdivided into two large and spatially discrete areas. Because they are different in elevation and tilt, these areas vary in stone quality, accessibility, and workability. When freshly quarried, the tuff is a distinctive yellow-orange (a color sought for its cultural associations with the chiefly class) but weathers to black.

In 1968, the initial phase of the first islandwide intensive archaeological site survey was begun under the auspices of Chilean governmental agencies. Large quantities of important data on prehistoric land use and subsistence patterns were collected. A more narrowly focused survey identifying and describing the moai was necessary, as these statues are key elements of the ritualized landscape and the focal points of social identity. In 1981, the moai inventory was organized in three phases. The statues contained in the surveyed quadrants of the island were inventoried first, followed by those in the nonsurveyed areas, and then those remaining in Rano Raraku. A detailed map of the Rano Raraku archaeological zone was published by the Universidad de Chile in 1981, but the interior quarries were not mapped. That task was undertaken in 2002 and is described here as the final stage of the inventory.

Moai, the stone statues of Rapa Nui. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

Quarry site showing several unfinished moai within the crater of Rano Raraku. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

Global Positioning System

Global Positioning System (GPS) was selected as the tool that most fulfilled the survey objective and allowed concordance with the 1981 map of the Rano Raraku environs. GPS is a navigation and mapping tool that employs special equipment to receive radio signals transmitted from a network of twenty-four satellites circling the Earth twice a day in precise orbits. It allows the rapid acquisition of detailed and comprehensive data with pinpoint accuracy. GPS is suitable for Rano Raraku's difficult terrain and requires minimal training. Importantly, the documentation team had access to GPS equipment and included a surveyor with experience and expertise.

Other survey tools were considered or tried during the planning stage. A total station was not available, nor did our team include a trained user for that equipment. Furthermore, the rugged, steep terrain and intrusive vegetation covering the statues eliminated the possibility of using a total station, because the line of sight would have been obstructed. Aerial photography to the required level of detail was either not available or insufficient. Traditional methods of sketching and hand measurements were routinely used at other statue sites but were not appropriate for efficient recording of such an extensive area.

Several satellites with known coordinates are orbiting the Earth at an altitude of 20,200 kilometers and are constantly emitting a unique radio frequency with different codes. Ground stations, strategically placed around the world, determine the location of the satellites. These ground stations also correct any distortion to the signal emitted by the satellite as it passes through the atmosphere. The GPS device is a radio receiver and minicomputer that can calculate the trigonometry required to determine its location relative to the satellites. These raw data are directly converted to latitudinal and longitudinal coordinates by the GPS unit.

Two categories of GPS radio receivers range in accuracy. For these two categories, accuracy can be improved to several centimeters with a differential signal, which is a ground-based radio transmitter. This base station transmits radio signals that supplement those from the satellites. Amateur or handheld GPS devices are not corrected by a ground-based station and range in accuracy between 5 and 15 meters. Professional or survey-grade GPS tools involve a ground-based signal to enhance accuracy to several centimeters. In addition, a professional GPS radio receiver has a larger antenna and is set on a 2.5-meter (adjustable) pole to increase the reception. The whole system, consisting of the antenna, pole, and radio receiver, is called a rover. The GPS rover unit receives signals from the satellites and base station.

Sophisticated GPS models, including the Promark 2 and Trimble systems, were used for data collection. These survey-grade models are light and user friendly, have much greater accuracy than handheld units to capture key features of the statues, and are more advanced in that they feature a built-in screen allowing the operator to communicate efficiently with the rover.

A team of seven carried out the survey and included an archaeologist, a surveyor, an artist, a database manager, and several field assistants. Data were gathered in the field over a period of three weeks and then processed in the lab over a two-month period. Minimal training was required to use the GPS unit; however, expertise in field survey methods and a comprehensive database management strategy were necessary.

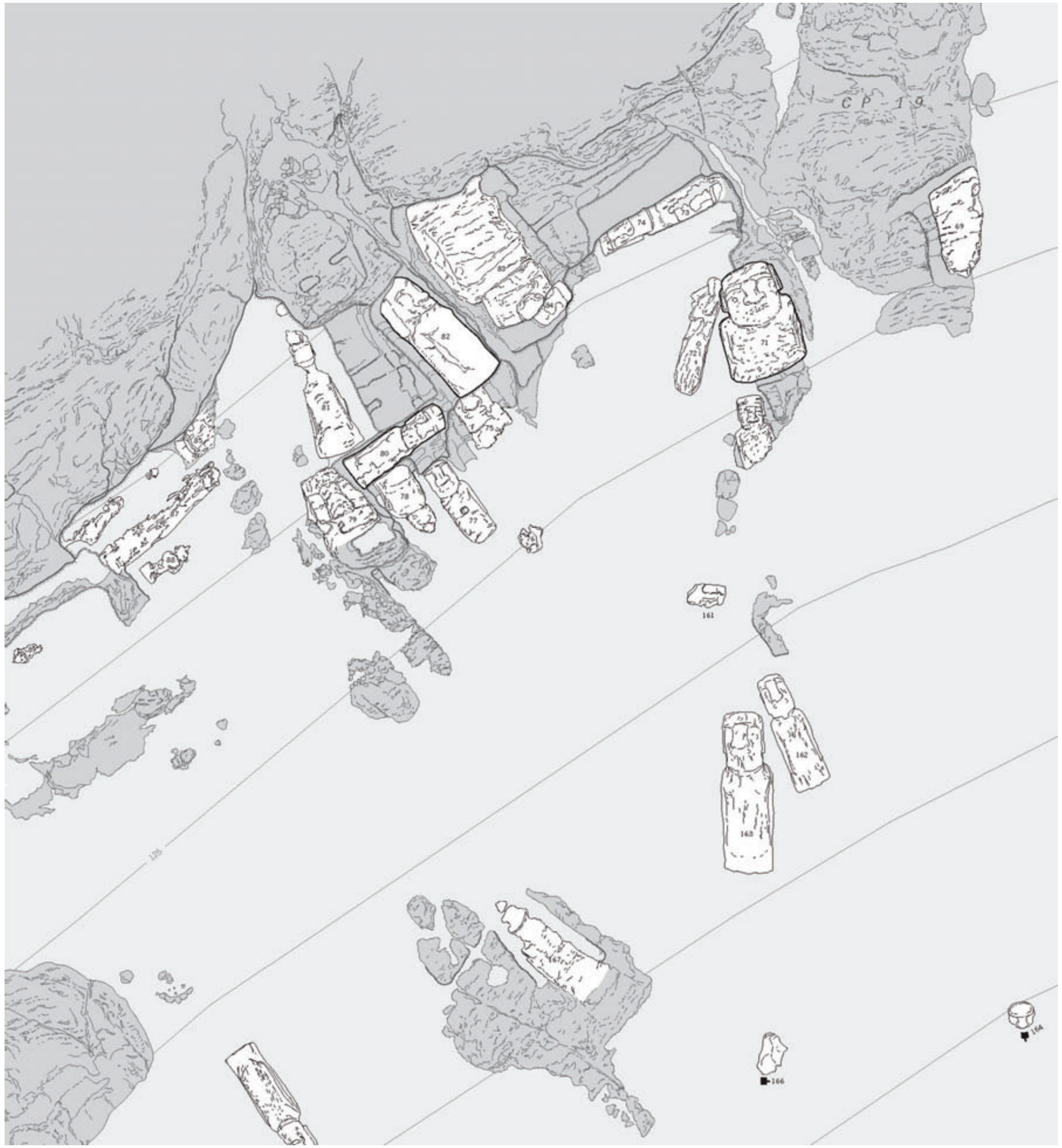
Fieldwork started with a reconnaissance of the statues and the site. The survey was established on the geodetic station known as Easter Island Laser Station – JPL 4008-S. This survey monument, created in 1992, is located 10 kilometers from the main base station and control point network in Rano Raraku. The team archaeologist located the statues and key features; the team artist, who had a trained eye in recognizing features of the statues, sketched the moai; and the team surveyor gathered GPS points.

Cristián Arévalo Pakarati (*left*) and surveyor Matt Bates collecting data using a GPS rover unit. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

The receiver used was a single-frequency system that required no cables and operated on standard batteries. This system is expandable, adaptable, light, and mobile and can achieve centimeter-level accuracy. In the Stop/Go surveying procedure that was used, one of two receivers was stationary and the other–the rover–was mounted on a survey pole. When the rover was held in front of the stationary receiver, contact was established via an infrared port and the units were synchronized.

The rover survey pole was mounted at precise points outlining statues, statue design characteristics, and quarrying or other archaeological features. The point identifications were entered into a handheld data collector by the surveyor and precisely recorded on a detailed sketch map. If the steeper walls of the volcano interfered with satellite transmission, the surveyor had to descend the slope to the control point and re-initialize. About three hundred points per day were collected.

Points were also taken on statues lying on slopes and free of the quarries. Statues standing upright and embedded in the ground lean at various angles from the vertical. Points were taken equidistant in front and behind each of these statues, giving the facing direction as well as the XYZ location. All data were downloaded to a laptop via the infrared connection and the receiver software. GPS points were imported to AutoCAD for manipulation and plotting. The survey was checked on site during data capture and reviewed every night. The data were backed up, archived on the island, and carried back to Los Angeles.



A portion of the finished map, generated from GPS data, showing the location and features of the unfinished moai within the quarry. Diagram: Alice Hom © Jo Anne Van Tilburg/Easter Island Statue Project.

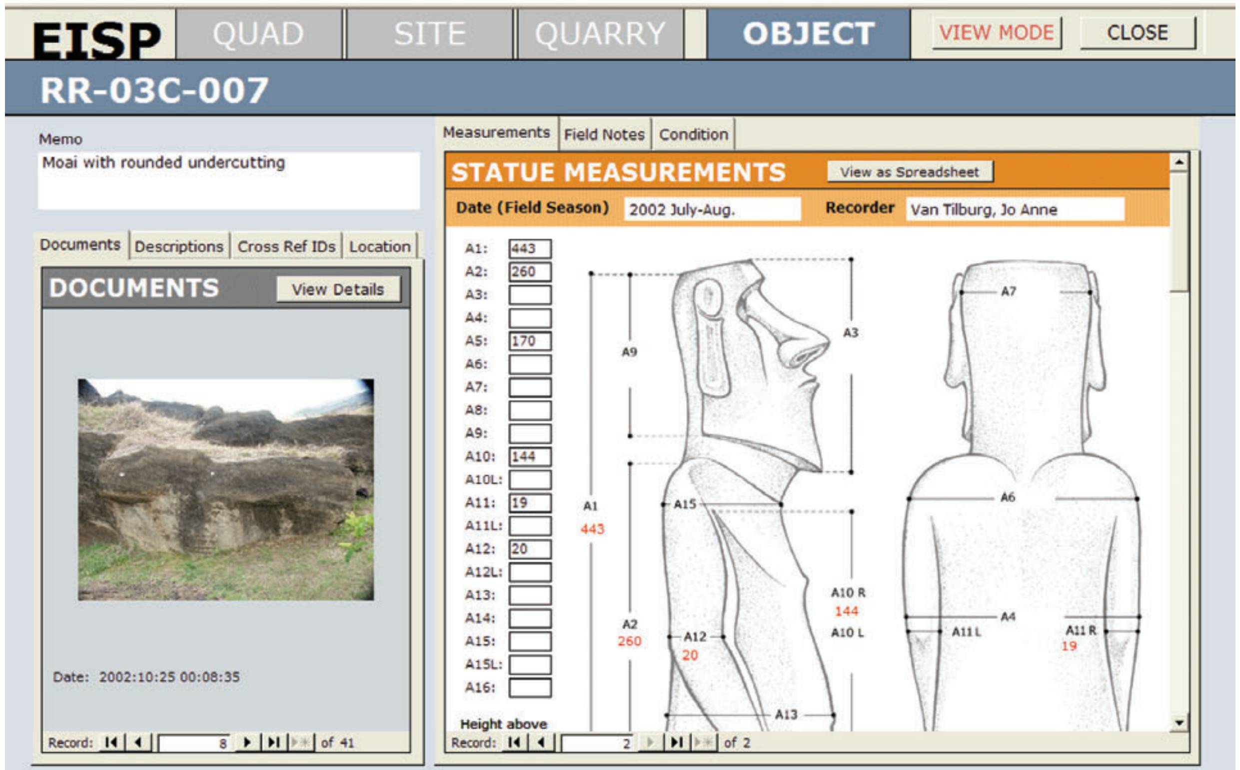
An Answer

Some difficulties were encountered during the survey process, attributed mainly to the difficult access of the rough terrain but also to some hardware failures. The receiver on the first GPS unit frequently dropped the signal and some survey points were lost. Also, data storage and output became increasingly problematic as the amount of information increased. GPS was successful in describing exposed and partially exposed features and in capturing size, proportion, and descriptive details of moai shape. GPS was also extremely efficient in covering a large landscape with a small team and limited time on site.

Upon the team's return from the field, the AutoCAD files were imported into Adobe Illustrator, which allowed for the best line quality in the final version. Work was based on the field sketches that had been scaled and morphed to fit over the survey points. The lines were redrafted with adjusted line weights to create figurative and artistic renderings of the moai rather than schematics. This supported and projected the reality of the quarry as a place not only where the statues were made but also where they were conceptualized as aesthetic objects. The map was reviewed in various draft stages during several field checks and informally by cartographers at UCLA and the National Geographic Society.

The innovative, localized, and visualized topographic and archaeological map of the interior of Rano Raraku will serve as the organizing and presentation tool for the project's massive database. This comprehensive, interactive, and searchable statue inventory and interfacing image catalogue contains more than twenty thousand images and the following categories of information on every

Screenshot of the EISP database, displaying a typical entry.
© Jo Anne Van Tilburg/Easter Island Statue Project.



statue: GPS map locators, site and statue-type definitions, measurements, field notes, stone surface condition reports, cross-reference identifiers, archived historical and ethnographic data, and survey and excavation histories.

Original records are preserved in the Easter Island Statue Project (EISP) archive, with full database working copies at UCLA and on Easter Island. Records are updated regularly. The full database ultimately will be disseminated as a controlled-access Internet feature, available to Chilean statutory authorities, professionals, and the Rapa Nui public. The EISP database is an analytical tool with significant research value. It allows visualization of historical and ecological linkages, supports the analysis of statue-type data in the context of social theory and the semiotics of spatial organization, and examines the statue corpus as a component of ecological, political, and esoteric systems.

Conservation observations of stone color, surface condition, and other variables were collected on all statues documented from 1981 to 2000. In 2002, the data collection categories were evaluated, updated, and consolidated. Initial analysis suggests an alarming rate of deterioration: every statue in Rano Raraku interior is in poor or extremely poor condition, with near-complete erosion and decomposition of stone surface and structural problems. The map, with its mass of linked and illustrative data, will provide a permanent record, enhance understanding of the Rapa Nui cultural heritage, and allow informed management, maintenance, and conservation efforts.

Dr. Jo Anne Van Tilburg is a research associate at the Cotsen Institute of Archaeology, University of California, Los Angeles, and director of the Easter Island Statue Project. She is considered one of the leading experts on the moai and has worked closely with the Rapa Nui community to inventory, describe, and protect the statues.

Cristián Arévalo Pakarati is a native Rapa Nui artist, graphic designer, and codirector of the Easter Island Statue Project.

Alice Hom is a graphic designer, illustrator, and database manager of the Easter Island Statue Project.

A Record for Posterity

Alonzo C. Addison

The world's cultural heritage is at risk—from climate change, natural disasters, inadequate conservation, tourism, armed conflicts, and simple neglect. On the arid coastal plain of Peru, the Incan earthen site of Tambo Colorado is facing such threats. The incremental loss of this fragile place is appalling, but worse perhaps is the loss of knowledge about the site and the ancient culture that built it. This is especially disturbing given that we have more tools and methods available today than ever before to record the physical characteristics of a site.

How can the site of Tambo Colorado be fully documented in order to safeguard the knowledge it contains for future generations?

A view of the earthen structures at Tambo Colorado, Peru.
Photo: © J. Paul Getty Trust.

Tambo Colorado, Peru

Situated between Lima and Nazca on Peru's hot, dry south-central coast, the richly painted fifteenth-century earthen adobe and stone ruins at Tambo Colorado are a fascinating glimpse back in time to the days of the Incan Empire. Thirty-five kilometers inland at the base of the Andes, located at the strategic entrance to the Pisco Valley, the site straddles the old Incan road to the highlands of Cuzco. Named *colorado* for its red painted walls, this waystation, or *tambo,* is thought to have been an Incan administrative center built for the integration of the conquered peoples of Ica and Chincha into the expanding empire. Adorned with archetypal trapezoidal doors and niches and featuring some of the original painted plaster, the site is among the best-preserved examples of Incan adobe architecture. Surrounding a large open plaza, the complex features a maze of small rooms and elements of both classic Incan imperial and local Chincha style, as well as extensive pre- and post-Incan vestiges.

Although known to the Spanish conquistadores (who, along with more recent generations, left their marks in graffiti), documentation did not begin until the turn of the twentieth century, when the site was first photographed by the American (Swiss-born) anthropologist and historian Adolph Bandelier. In 1901, the German archaeologist Max Uhle produced maps and took numerous photographs and extensive notes. Uhle's records reveal the sad toll that windborne sand, intermittent rain, vandalism, looting, roadwork, and cattle ranching have taken. Despite deteriorating conditions, a majority of the adobe walls in the prominent structure known as the Northern Palace are still standing, and a surprising amount of paintwork is still visible, both in niches and as large horizontal bands of alternating red, yellow, and white on the outer walls.

Outer wall of the Northern Palace, showing remnants of the original plaster and paint. Photo: © Alonzo Addison.

Example of structural damage to the earthen adobe walls of the Tambo complex. Photo: © Alonzo Addison.

In 2001 (the centenary of Uhle's visit), Dr. Craig Morris of New York City's American Museum of Natural History, Professor Jean-Pierre Protzen of the University of California at Berkeley, and the author launched a research effort to develop an integrated digital record of the site and thoroughly document its condition before it suffered further damage. Over the course of four summers, Professor Julian Idilio Santillana of Peru's Pontificia Universidad Católica, Dr. Maurizio Forte of Italy's Istituto per le Tecnologie Applicate ai Beni Culturali, and a number of graduate students from these schools and institutions worked with UC Berkeley's Center for Design Visualization and Archaeological Research Facility to create an extensive digital record of the main complex and outlying buildings and landscape.

Tambo is a complex site. Ranging across an area roughly 13 square kilometers, it features everything from small artifacts recovered in excavations to hillside burials and large storage sites, as well as painted adobe and stone walls in the main compound. No single technology can suitably record this diversity of materials and range of scale. With the wide variety of tools and techniques available today to capture the geometry and dimensional characteristics of built heritage, the challenge was to select the most appropriate technologies and integrate the results into a complete record for posterity.

Laser Scanning

Given the site's architectural scale and the desire for a detailed dimensional record of the eroding adobe walls, laser scanning was selected as the primary tool for its ability to capture irregular surfaces. Having evolved from developments in measurement devices for mechanical engineering and manufacturing, laser scanners have seen growing acceptance in the past few years for recording archaeological sites. Unlike a surveying instrument, which captures single important points such as the corners of walls, a laser scanner can capture large irregular and eroded surfaces. For architectural-scale built heritage, the speed, accuracy, and "noncontact" characteristics of laser scanning offer new possibilities for acquiring data of 3-D objects.

Three-dimensional laser scanning technologies are generally based on one of three methods: (1) time of flight, a technique by which a laser pulse is emitted from the instrument and the time of (light) travel is measured, from which distance to the object can be determined (since the speed of light is a known constant); (2) phase comparison, in which the instrument emits light with a known frequency and phase, and distance to the object can be determined by comparing the emitted phases to the returned phases; and (3) triangulation, in which an emitter and a receiver, separated by a known distance, record the angle of the reflected laser pulse to determine distance (using the Pythagorean theorem). With these technologies, XYZ coordinates are recorded as millions of individual points. Close together, these points form a dense "point cloud" that represents an object. These individual points must be connected together ("meshed") to create a 3-D model.

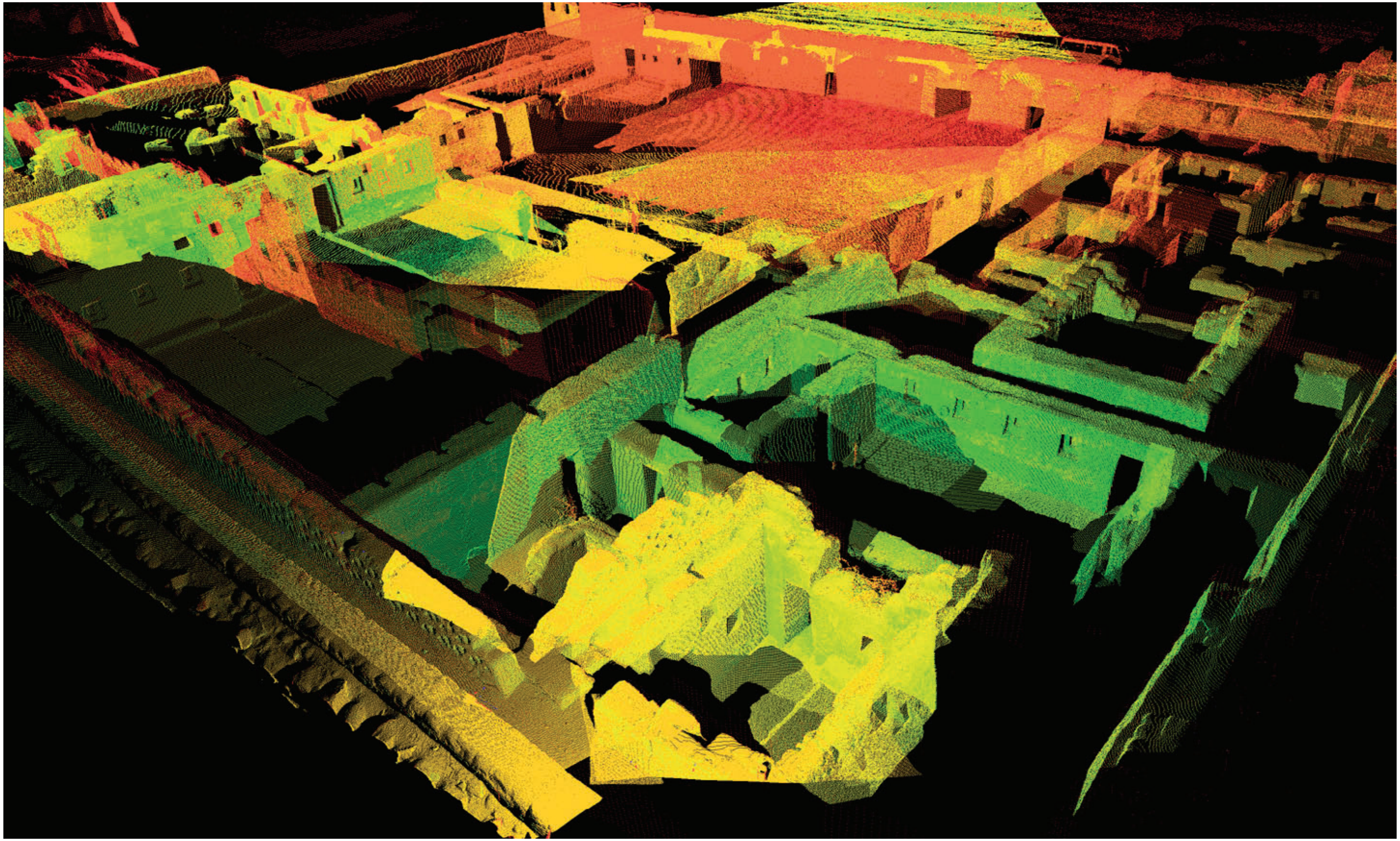
These scanning technologies are used for different purposes based on the distance from the sensor to the object and the speed and level of precision required. Triangulation scanners are best for shorter ranges and for greater precision and detail. Phase comparison is good for short or long range where speed is needed, but at the expense of some accuracy. Time-of-flight technology, also known as light detection and ranging (LIDAR), is used for larger sites and buildings where survey accuracy is needed. Typical distances for long-range systems vary from a minimum of 1 to 2 meters to a maximum of hundreds of meters. This range and resolution makes time-of-flight technology perfect for the recording of architectural- or archaeological-scale features and objects.

There are several important considerations when utilizing laser scanners in built heritage. The choice of device will be guided by type and size of site, required accuracy, budget (costs range from thousands to hundreds of thousands in U.S. dollars), and the goals of the project. Not all laser scanning systems are field operable: battery life, operability in bright sunlight (which can wash out the beam to the point where the return pulse cannot be measured), ruggedness, size, and weight should be considered when selecting a system.

For this project, a Cyrax 2400/2500 (which became the Leica HDS 2500), a long-range (1 to 100 meters) time-of-flight system, was chosen. It was field operable (powered by eight-hour rechargeable battery packs), laptop controlled, and ruggedized, a crucial consideration given the pervasive sand and glare at the site.

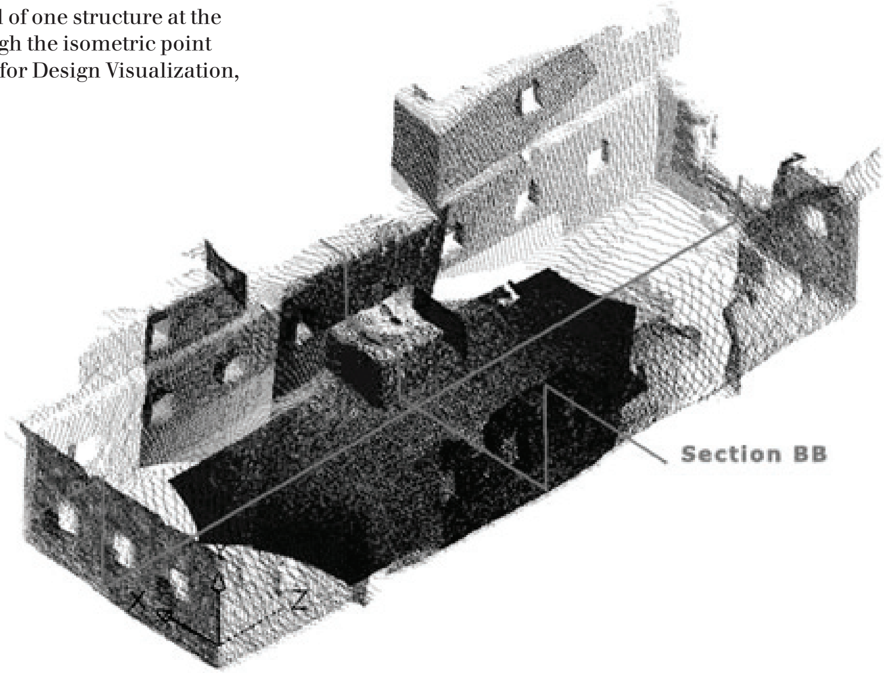
Although laser scanning was chosen as the primary documentation method, given the variety of information needed, a range of other technologies was also used to create a thorough and complete record. Differential Global Positioning System (DGPS) was used with aerial and satellite photography to spatially locate burials and place the laser surveys in context. Some additional close-range overhead imagery was gathered with aerial kite photography. Digital photography with a color chart was utilized to capture Tambo Colorado's vivid paint remnants and to provide "textures" for the laser scans. Panoramic lenses were used to capture QuickTime VR 360-degree images for context visualization. Time-lapse photography and video were also used to record ongoing archaeological excavations. Survey instruments (e.g., a total station theodolite) were used to measure control targets and assemble data from the large number of scans from different positions. Handheld and laptop computers and a custom database were used for data management, and a close-range triangulation laser scanner was utilized for fine details and to experiment with making a layer-by-layer 3-D volumetric record of an ongoing archaeological excavation.

The documentation team at Tambo Colorado preparing to use the Cyrax 2400/2500 (which became the Leica HDS 2500) long-range laser scanner. Photo: © Alonzo Addison.



The point cloud generated by laser scanning technology, representing the Tambo site. Image: © Courtesy Center for Design Visualization, UC Berkeley.

Top: Isolated isometric point cloud of one structure at the site. *Bottom:* A cross section through the isometric point cloud. Images: © Courtesy Center for Design Visualization, UC Berkeley.



An Answer

Laser scanning provided an ideal solution to record the complex and irregular surface geometry of the remaining adobe walls of this site and its smaller architectural details. As part of an integrated digital tool kit, the technology formed the foundation for a 3-D information archive of current conditions, allowing measurements to be extracted, reconstructions to be visualized, and field notes and photographs to be integrated by location.

Although an important tool in the conservator's arsenal, laser scanning is only one piece of a larger puzzle in base recording and is well suited to being part of a suite of digital technologies. In any project like this one, where data may be in proprietary formats or on limited life-span digital media, it is important to ensure the record will survive. A simple data preservation solution is to print out all information on archival paper and submit it to a library or international archive. A printed record can always be redigitized if the digital records become unusable through equipment or media failure or obsolescence.

Alonzo C. Addison serves as special adviser to the World Heritage Centre, UNESCO, on issues of applied technology. He was involved in developing strategies for one of the first commercially viable laser scanners for Cyra Technologies and its 3-D monument-scale LIDAR scanner in the 1990s. A cofounder of the Virtual Heritage Network, his work ranges from historical visualization to design simulation, information architecture, and collaborative networks. His interests lie in the nexus of digital technology, world heritage conservation, and design, and he has written extensively on these subjects.